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Photoelectric injection amplification of Al–Al₂O₃–p–CdTe–Mo structures at low bias voltages

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Abstract

The results of studies of photoelectric injection enhancement of the Al–Al₂O₃–p–CdTe–Mo structure upon application of low bias voltages. It has been shown that the studied Al–Al₂O₃–p–CdTe–Mo structure under can be represented as a n^+p-R_{om} structure with a long base. Conducted researches show that Al–Al₂O₃–p–CdTe–Mo structure has unique properties. It has very high photocurrent and photosensitivity at both direct and reverse bias voltage under even small bias voltage (up to 500mV).

Keywords: MOS structure, film, injection photodetector, photocurrent, spectral sensitivity

PACS 72.10.-d, 73.61.Ga, 73.40.Sx

1. Introduction

In [1-4], detector structures with Schottky barrier made on the basis of various materials were investigated, but in these structures the base has always been monocrystal. However, as shown in [5], large-block polycrystalline CdTe films with a columnar structure of grains (crystallites) can be used as the base material. On the basis of such films of cadmium telluride, we were the first to obtain an injection photodetector [6]. The creation of injection photodetectors based on A₂B₆ seems to be an urgent and promising task, since these materials have a band gap corresponding to the full spectrum of visible and partially ultraviolet light, they are characterized by direct optical transitions, which makes it possible to obtain a high efficiency of generation of electron-hole pairs. Hence, the

aim of this work is to study the processes of injection amplification in the Al-Al₂O₃ – *p*-CdTe-Mo structure, created on the basis of one of the semiconductors of the A²B⁶ type — cadmium telluride.

2. Samples and measurement procedure

To solve this problem, we obtained *p*-CdTe film structures with a columnar structure of grains on a Mo substrate by sublimation in a hydrogen flow. It should be noted that when using hydrogen as a carrier gas, the transport of the vaporized substance is carried out at relatively lower temperatures than in the case of other inert gas compositions. In the synthesis of CdTe films in a flow of hydrogen H₂, the determining factor affecting their growth rate is the degree of excess of the metal components of cadmium vapor in the stoichiometric composition. This is explained by the fact that the components of Cd atoms are more volatile relative to Te atoms in CdTe vapor and is confirmed by the results of studies of the microstructure of the surface of the Al-*p*-CdTe-Mo structure on the surface of the CdTe film, as well as on the surface of aluminum. The elemental composition of the structure was studied using a Jeol JXA-8900R electron microprobe analyzer and a LINK ISIS energy dispersive spectrometer (EDS) (Japan). It was revealed that the atomic ratio of the components in the CdTe film is Cd/Te=0.986≈1, which corresponds to the weak *p*-type conductivity of CdTe. Microcrystals of CdTe films grown at a substrate temperature T_s = 670°C are high-resistivity ($\rho = 10^9 \div 10^{11}$ Ω·cm) and have a mixed - hexagonal and cubic structure. They have a columnar grain structure in the direction of growth and were practically a single crystal. The cross-sectional grain sizes range from 100 to 150 μm. The thickness of the *p*-CdTe films was initially 40-50 μm, so that the grains penetrate the entire thickness of the film. The films obtained by grinding and polishing were brought to the required thickness (8 -10 μm), since at base thicknesses $d \leq 5$ μm, the Al-*p*-CdTe-Mo diode structure sharply loses its rectifying properties. For example, the rectification coefficient, defined as the ratio of forward and reverse current at a fixed voltage (5 V), with a base thickness $d = 8-10$ μm is four to five orders of magnitude, and at $d \approx 5$ μm it is only two orders of magnitude at the same value bias voltage. This is

explained by the fact that the number of structural defects, including various complexes and inclusions in the growing film at a distance of $\sim 5 \mu\text{m}$ from the molybdenum substrate begins to increase sharply. The base thickness of the structure under investigation is $d \approx 10 \mu\text{m}$. MOS structures were created on the surface of the films obtained by sputtering aluminum (Al) in vacuum ($\sim 10^{-5}$ Torr) [7]. In this case, the frontal aluminum contact had a thickness of $\sim 40\div 50 \text{ nm}$ and an area of $S \approx 1 \text{ cm}^2$. Here, the role of the rear electrical contact is played by the Mo substrate. The performed X-ray structural analysis showed [8, 9] that a thin oxide layer of Al_2O_3 with a thickness of $\sim 30 \text{ nm}$ is formed in the performed technological process. This layer plays a very important role in the operation of the resulting structure; it is thanks to it that not a simple metal-semiconductor structure is obtained, but a MOS structure, i.e. Al- Al_2O_3 - p -CdTe-Mo (Al metal, Al_2O_3 oxide, CdTe semiconductor). It is well-known from literature, that Al_2O_3 is n-semiconductors. Thus, the obtained Al- Al_2O_3 - p -CdTe-Mo- structure can be represented as $R_{\text{om}}-n^+-p-R_{\text{om}}$ a structure with a long p -base, the diagram of which is shown in Fig. 1.

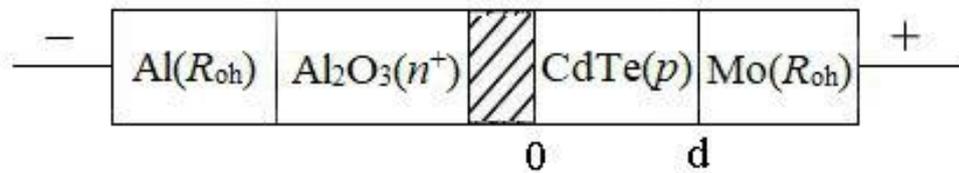


Fig. 1. Scheme of Al- Al_2O_3 - p -CdTe-Mo - structures.

3. Experimental results

The spectral dependence of the photocurrent $I_{ph}(\lambda)$ of the Al- n - Al_2O_3 - p -CdTe-Mo structure in the absence of a bias voltage in relative units is shown in Fig. 3a. It can be seen from the figure that the curve of the spectral dependence of the photocurrent $I_{ph}(\lambda)$ lies in the range wavelengths $400 \div 1000 \text{ nm}$. The dependence of the photocurrent $I_{ph}(\lambda)$ from the wavelength $\lambda \approx 400 \text{ nm}$ begins to grow slowly to $\lambda \approx 500 \text{ nm}$, and at $\lambda \approx 430 \text{ nm}$ a small jump is observed, and then at

$\lambda \approx 470$ nm there is a slowdown. Further, in the wavelength range of 500–700 nm, the photocurrent increases faster than in the first region. The $I_{ph}(\lambda)$ dependence has a peak at a wavelength of $\lambda \approx 750$ nm. Further, in the wavelength range of 750 ÷ 860 nm, the photocurrent value decreases with an increase in λ , and in the 860 ÷ 878 nm wavelength range, the rate of I_{ph}

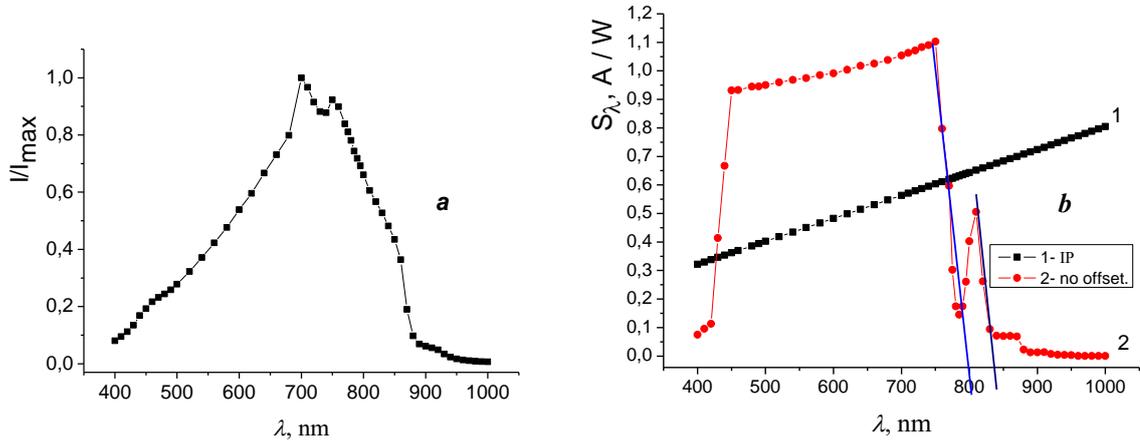


Fig. 2. Spectral dependence of (a) photocurrent and (b) photosensitivity of the Al- n^+ -Al₂O₃- p -CdTe- n -MoO₃-Mo structure (curve 2) and an ideal photodetector-IP (curve 1) in the absence of bias voltage.

decrease increases. Then the dependence $I_{ph}(\lambda)$ begins to decrease slowly with an increase in λ and at $\lambda \approx 1000$ nm reaches its minimum value.

In order to determine the efficiency of photon detection by the structure under study, in [10], we investigated the spectral sensitivity (S_λ) of the structure in the absence of bias, and also calculated S_λ for an ideal photodetector (IP) in the spectral wavelength range of 400–1000 nm. The spectral photosensitivity of the structure was measured on a 3MP-3 monochromator at room temperature (300 K), the radiation power was calibrated in absolute units using a thermoelement with a quartz window of the PHT-10 type.

We compare obtained data with results for ideal photodetector. An ideal photodetector means a photodetector in which all incident photons are absorbed and generate electron-hole pairs, which are separated without loss by a potential barrier and contribute to the photocurrent. Parameter $S_{\lambda id}$ for an ideal photodetector was calculated by the formula $(e/h\nu)\lambda\eta_\lambda(1-R)$, η_λ —is the internal quantum

efficiency, R is the reflection coefficient. In the calculation, the following values were taken: $\eta_\lambda = 1$, $R = 0$. It was shown that the structure under study operates as an injection photodetector and enhances the primary photocurrent even in the absence of an external bias voltage. It was found that at $\lambda=450$ nm, the spectral sensitivity $S_\lambda \approx 0.93$ A/W, which is 2.3 times greater than $S_{\lambda id}$. ideal photodetector at a given wavelength, and at $\lambda=750$ nm $S_\lambda \approx 1.1$ A/W.

As is known, injection photodetectors have two amplification mechanisms: positive feedback (PF) [11, 13] and parametric amplification (PA) [11, 12]. However, the results of the study on the spectral dependence of the photocurrent- I_{ph} and spectral sensitivity- S_λ do not allow one to say unambiguously which of the mechanisms of the primary photocurrent amplification takes place in the samples under study. This question is answered by studying the $I_{ph}(\lambda)$ and $S_\lambda(\lambda)$ dependences when the bias voltage is applied to the structure. Therefore, the dependences $I_{ph}(\lambda)$, $S_\lambda(\lambda)$ were investigated when the bias voltage was applied to the structure both in the forward (Fig. 3) and reverse (Fig. 4) directions of the current.

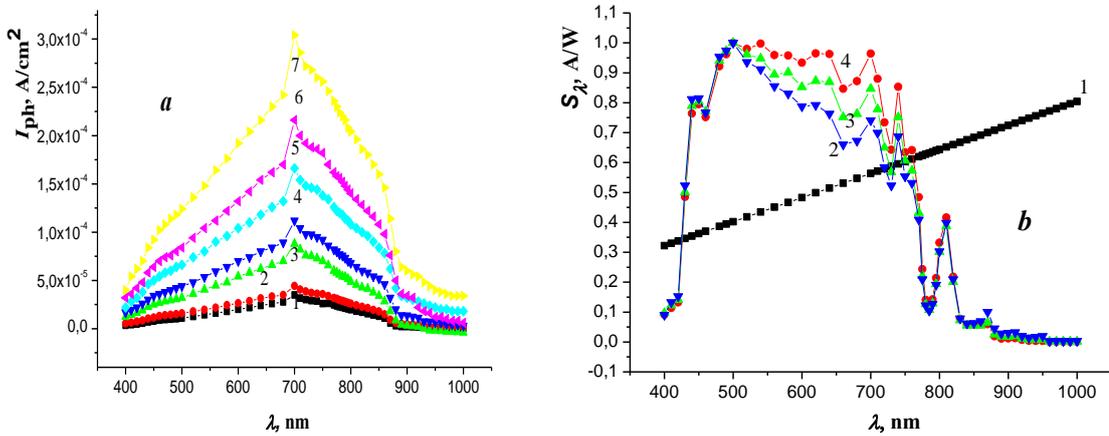


Fig. 3. The spectral dependence of the photocurrent- I_{ph} (a) and the spectral sensitivity- S_λ (b) of the Al-Al₂O₃-p-CdTe-Mo structure at various bias voltages : at the forward direction of the current. a) 1.-10, 2.-60, 3.-150, 4.-200, 5.-300, 6.-400, 7.- 500 mV; b) 1.-IF, 2.-10, 3.-60, 4.-500 mV and an ideal photodetector (IF, kr.1) at the absence of bias voltage.

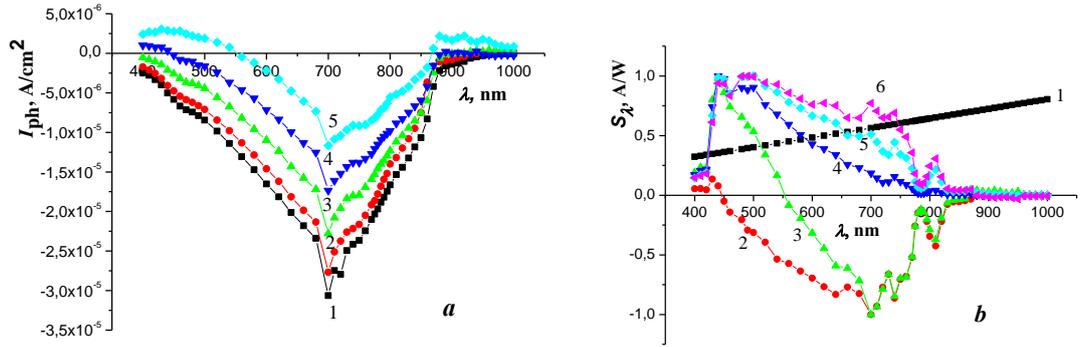


Fig. 4. Spectral dependence of photocurrent- I_{ph} (a) and spectral sensitivity- S_{λ} (b) of the Al – Al₂O₃ – *p*-CdTe – Mo structure at reverse bias voltages: a) 1.-10, 2.-20, 3.-40, 4 .-60, 5.-80; b) 1.-10, 2.-60, 3.-80, 4.-150, 5.-300, 6.-500 mV and an ideal photodetector (IF, kr.1) at the absence of bias voltage.

4. Discussion

First, let us analyze the dependence $I_{ph}(\lambda)$ when applying low bias voltages of various magnitudes in the forward direction of the current when a negative potential is applied to the Al- contact (see Fig. 3a). As seen from Fig. 3a, the value of the photocurrent increases with an increase in the bias voltage in the entire spectral sensitivity range of the structure, and the current increases faster in the short-wavelength and long-wavelength regions of the spectral range as compared to the medium wavelength. For example, $I_{ph}=3.2 \cdot 10^{-6} \text{ A/cm}^2$ at $\lambda=400 \text{ nm}$ in the absence of a bias voltage, and when 500 mV is applied, its value increases 18 times, in the spectrum range $\lambda=600\text{--}700 \text{ nm}$, the current increases 9 times, and at $\lambda=1000 \text{ nm}$, the current increases 207 times. It should be noted that the greatest increase in the photocurrent is observed in the long-wavelength region of the spectral range.

Analysis of the $S_{\lambda}(\lambda)$ dependence shows that its dynamics of spectral sensitivity change is the same as for the $I_{ph}(\lambda)$ dependence, therefore, the degree of increase in S_{λ} is the same as for I_{ph} at the same bias voltage and wavelength of light radiation (see. fig.3a and b). This is not surprising, since when the bias voltages are applied, only the photocurrent increases, while the incident radiation power remains constant. Therefore, the same degree of growth is observed in the

values of I_{ph} , S_λ . A more intense increase in the values of I_{ph} and S_λ is observed in the short-wavelength and long-wavelength regions of the photosensitivity spectrum, as compared to the mid-wavelength region of the spectrum of 450–750 nm.

Let us now discuss the data on the spectral dependence of the photocurrent obtained when low reverse bias voltages of various magnitudes are applied to the structure (Fig. 4). From

these figures it follows that the photocurrent when low reverse bias voltages ($V \geq 10$ mV) are applied has the opposite direction to the photocurrent obtained I_{ph} in the absence of bias voltage (ie negative sign) in the entire spectral range of photosensitivity (400–1000 nm). In this case, the shape of the $I_{ph}(\lambda)$, $S_\lambda(\lambda)$ dependences is the same as at $V=0$ mV. With an increase in the bias voltage, the absolute value of the photocurrent decreases, and gradually its values in the short-wavelength part of the spectrum acquire a positive value. At $V=60$ mV, the photocurrent, crossing the abscissa at $\lambda=440$ nm, acquires a positive value equal to $3.4 \mu\text{A}/\text{cm}^2$ ($S_\lambda=0.07$ A/W). With a further increase in V_{cm} , the photocurrent inversion point shifts toward longer waves, while the positive I_{ph} value increases and its spectral range expands. For example, the photocurrent inversion point shifts by 110 nm from $\lambda=440$ nm to $\lambda=550$ nm when the bias voltage changes from $V_{cm}=60$ mV to $V_{cm}=120$ mV. At a bias voltage $V_{cm}=150$ mV, the photocurrent is completely positive in the entire spectral range of photosensitivity. It should be noted that when $V_{cm}=80$ mV is applied, the value of photosensitivity becomes greater than S_λ of an ideal photodetector in the spectral range of 430–500 nm. Moreover, with a further increase in the value of the applied bias voltage, the region of the spectrum, where $S_\lambda > S_{id}$, expands. For example, at $V_{cm}=500$ mV, it covers the spectrum range of 430–740 nm.

5. Conclusion

As noted above, two mechanisms of injection amplification are possible - positive feedback and parametric amplification, when not only the concentration of charge carriers in the bulk of the high-resistance semiconductor increases, but also

the parameters, in particular the lifetime, change. The structure under study has a highly resistive, strongly compensated base, which means that the nature of impurity centers and the capture of carriers on them can play a significant role in all current amplification processes; therefore, the final elucidation of the physical mechanism of injection amplification processes in this structure requires further research at higher current densities.

References

- [1.] H. KAnbur, Ş. Altındal, T. Mammadov, Y. Şafak. “Effects of illumination on I - V , C-V and G/w-V characteristics of Au / n - CdTe Schottky barrier diodes”, *Journal of Optoelectronics and Advanced Materials*, vol. 13, no. 6, pp. 713 – 718, 2011.
- [2]. Ö. Vural, Y. Şafak, Ş. Altındal, A. Türüt. “Current-voltage characteristics of Al/n-GaSa structures in the wide temperature range”, *Current Applied Physics*, vol. 10, no. 3, pp.761 – 765, 2010.
- [3]. E. Marıl, A. Kaya, S. Koçyiğit, Ş. Altındal. “On the analysis of the leakage current in Au/Ca₃Co₄Ga_{0.001}O_x/n-Si structure in the temperature range 80 – 340 K”, *Materials Science in semiconductor Processing*, vol. 31, pp. 256 – 261, 2015.
- [4]. S. Demirezen, A. Kaya, Ö. Vural, Ş. Altındal.”The effect of Mo-doped PVC+TCNQ Interfacial layer on the electrical properties of Au/PVC+TCNQ/p-Si structures at room temperature”, *Materials Science in Semiconductor Processing*, vol. 33, pp. 140- 148, 2015.
- [5]. *Polikristallicheskiye poluprovodniki*, Pod redaktsiyey G. Kharbeke, [*Polycrystalline semiconductors*, Edited by G. Harbeke.], M.: Mir, 1989, p.341.
- [6]. Mirsagatov Sh.A., Uteniyazov A.K. “Injection Photodiode Based on p-CdTe Film”, *Technical Physics Letters*, vol. 38, no. 1, pp. 34-37, 2012.
- [7]. Mirsagatov Sh.A., Uteniyazov A.K., Achilov A.S. “Mechanism of Current Transport in Schottky Barrier Diodes Based on Coarse-Grained CdTe Films”, *Physics of the Solid State*, vol. 54, no. 9, pp. 1643-1654, 2012.

[8]. Sh.A. Mirsagatov, S.A. Muzafarova, M.S. Baiyev, A.S. Achilov. “Issledovaniye real'nogo stroyeniya dioda s bar'yerom Shottki Al-p-CdTe” [The study of real structures of a diode with a Schottky barrier Al-p-CdTe], *Uzb. physical journal*, no. 12, pp. 154-160, 2010 (of Uzbekistan).

[9]. A.S. Achilov, B.N. Zaveryukhin, M.U. Kalanov, V.M. Rustamova. “Rentgenovskiye issledovaniya struktury novogo tipa A_2B_6 priyemnika elektromagnitnogo izlucheniya” [X-ray studies structures of a new type of A_2B_6 receiver of electromagnetic radiation], *Reports of the Academy of Sciences RUz.*, no. 2, pp. 24-26, 2014 (of Uzbekistan).

[10]. A.K. Uteniyazov, K.A. Ismailov. “Spektral'noye raspredeleniye fotochuvstvitel'nosti struktury Al- Al_2O_3 -p-CdTe-Mo” [The spectral distribution of photosensitivity Al- Al_2O_3 -p-CdTe-Mo tours], *Reports of the Academy of Sciences RUz.*, no. 5, p. 27-31, 2019 (of Uzbekistan).

[11]. I.M. Vikulin, Sh.D. Kurmashev, V.I. Stafeyev. “Injection-Based Photodetectors”, *Semiconductors*, vol.42, no. 1, pp. 113-127, 2008.

[12]. V.I. Stafeyev. “Fotopriyemniki IK diapazona na osnove $Cd_xHg_{1-x}Te$, na primesnykh poluprovodnikakh (Ge i Si) i UF diapazona na osnove soyedineniy A_2B_5 ” [IR photodetectors based on $Cd_xHg_{1-x}Te$, based on impurity water reservoirs (Ge and Si) and the UZI range based on A_2B_5 compounds], *35 years of work at the Research Institute of Applied Physics (1970-2005)*. M.: Orion, 2008 (in Russian).

[13]. V.I. Stafeyev. “Elektronnyye pribory na osnove poluizolyatorov” [Electronic devices based on semiinsulators], *Technology and Design statement in electronic equipment*, no. 5, p. 3-13, 2007 (in Russian).